Ultra-Precision Machine Spindle Using Porous Ceramic Bearings

P. Geraghty, K. Carlisle, L. Hale

Air-bearing spindles have typically been employed for ultra-precision machine applications, due to the low asynchronous error motion and the high rotational accuracies achievable. Traditional oil-fluid-film bearings have not been able to match the accuracies of air bearings, but they have the advantage of higher stiffness and improved dampening capabilities. With the advent of new oil-fluid-film porous ceramic bearing materials, we may now be able to have the best of both worlds: the accuracy of an air bearing with the high stiffness and improved dampening capabilities of a traditional oil-fluid-film bearing.

Fluid-film and air-film bearings have been used for machine spindles whenever precision motion requirements exceed the capabilities of traditional contact bearings. For example, in the 1970s, "T"- based lathe spindles used contact (ball or roller) bearing technology. A quantum leap in spindle accuracy was achieved when these spindles were replaced with porous graphite air-bearing spindles.

In the late 1970s and early 1980s, LLNL led in the field of high-precision diamond-turning machining, using porous graphite air-bearing spindles. Machines such as DTM #1, DTM #2, DTM #3, and LODTM all pushed the field of precision diamond turning to higher and higher levels of accuracy. Though 20 years old, these machines still operate at the limits of current machine accuracies.

LLNL is now designing the next-generation machine tool. Precision Optic Grinder and Lathe (POGAL) is the next machine that will push the limits of accuracy farther still. POGAL is required to have spindle accuracies of less than 50 nm in both axial and radial directions.

In addition to the precision requirements of POGAL, there is also an increasing demand for larger parts requiring diamond turning that is reaching the load capacity of air-bearing spindles. Precision grinding of hard optics, a capability of POGAL, is also on the increase, requiring greater stiffness and damping from our machine spindles.

This all leads to the use of hydrostatic oil-film bearings. When compared to air bearings, hydrostatic oil bearings have higher stiffness, higher load capacity, and better damping characteristics. The problem is conventional oil-film-bearing spindles have not been able to match the accuracies achievable with air-bearing spindles.

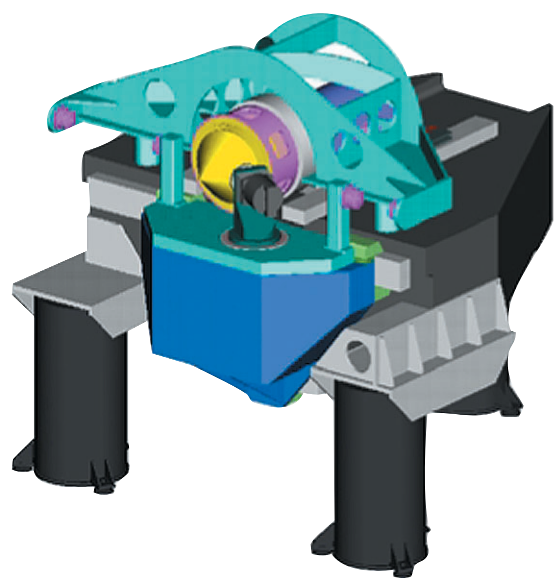
The materials science laboratory at Cranfield University, UK, has developed and commercialized the production of a porous ceramic bearing material, which is now readily available. It is hoped that with this new ceramic material, we may now be able to get the accuracy of an air-bearing spindle with the high stiffness and improved dampening capabilities of a traditional oil-fluid-film-bearing spindle.

As part of the initial phase of this project, we are collaborating with staff at Cranfield Precision, UK, to design an ultra-precision machine spindle using this new material. This spindle has been designed to meet the requirements of POGAL.

This is a two-year project. The goals of this first year were to: 1) design a porous-ceramic-bearing spindle that meets the requirements of POGAL; 2) prepare a complete engineering package, including assembly drawings, detail drawings, tooling drawings, and engineering analysis; and 3) generate a mathematical model to predict the performance of the spindle.

We have achieved all three goals. Additionally, the long lead-time material was ordered and received, in preparation for spindle fabrication next year.

The spindle will be built and tested next year.



Conceptual drawing of the new POGAL machine, the next-generation machine tool being designed at LLNL.